Chapter 1

Veto

The most important reason for locating sensitive detectors deep underground is to eliminate the background events caused by cosmic ray muons that originate in the atmosphere of the Earth. Muons are the most numerous cosmic ray charged particles at the surface of the Earth. They are produced in the upper atmosphere by the collision of cosmic ray primaries (protons, and nuclei); and they lose about 2 GeV in the atmosphere before reaching the surface.

Only muons and neutrinos penetrate to significant depths underground. The muons produce tertiary fluxes of photons, electrons, and hadrons. The goal of the underground laboratory is to reduce all such sources of backgrounds by shielding the detectors under rock. The shielding is commonly expressed as either ft of standard rock (with density of 2.65 gm/cc) or in meters-waterequivalent (mwe). As muons penetrate underground they lose energy by ionization and by radiative processes.

1.1 Depth Requirements for Physics

1.1.1 Accelerator Neutrinos

The high granularity of the detector will allow removal of cosmic muons from the data introducing a small ($< 0.1\%$) inefficiency to the active detector volume, so that most of the accelerator induced events are unobscured. The rate of muons in the detector at the 800 level is $0.06 Hz/m^2$ or $\approx$ 1 Hz/APA cell. During a drift time of 1.5 msec, 0.003 cosmic rays will pass through the active volume of one APA cell, resulting in a timing rejection factor of $\approx$ 800. In short, a cosmic ray veto is not required to study accelerator neutrino interactions.

1.1.2 Nucleon Decay

The depth requirement for proton decay experiments is dominated by the livetime loss due to event overlap with cosmic ray muons. A liquid argon detector will have much less deadtime loss at shallow depths than a water cherenkov detector as the fine segmentation in space and drift time allow one to exclude regions of the detector around each passing muon. Bueno et al.[12] **FIXME:** *need reference* estimate an effective loss of detector mass of less than 4% for a 100 kT liquid argon detector (GLACIER) with mountainous overburden of only 200 m with the use of a veto.

The most serious source of nucleon decay background for the νK^+ mode are K_L^0 mesons produced by cosmic ray spallation in the rock surrounding the detector. The effective interaction length of these K0's in liquid argon is 86 cm. These neutral kaons may enter the detector and produce a K^+ via charge exchange. Cosmic ray muons that pass through the rock near the cavern wall at small zenith angle as shown in figure 1.1.1 are the largest contribution to the background. Muons traveling at a larger zenith angle are unlikely to produce a forward going K0 that is unaccompanied by the interacted muon.

The GLACIER detector concept is an upright cylindrical tank of 20m height x 70m diameter. The tank is surrounded by annular veto detectors that extend 3m into the surrounding rock. An additional 3 - 5 meter fiducial cut was made inside the detector to reduce the spallation background in the νK^+ channel to 0.1 event per year. In contrast, we propose to extend the veto 7m into the rock to obviate the need for a fiducial cut. The interaction length of rock is roughly half the interaction length of liquid argon, so each meter of rock should provide equivalent attenuation of neutral kaons as two meters of liquid argon.

The veto described in the following section is designed to reduce the background in the νK^+ mode to a negligible level based on these arguments. Monte Carlo simulation of the proposed veto system is clearly required.

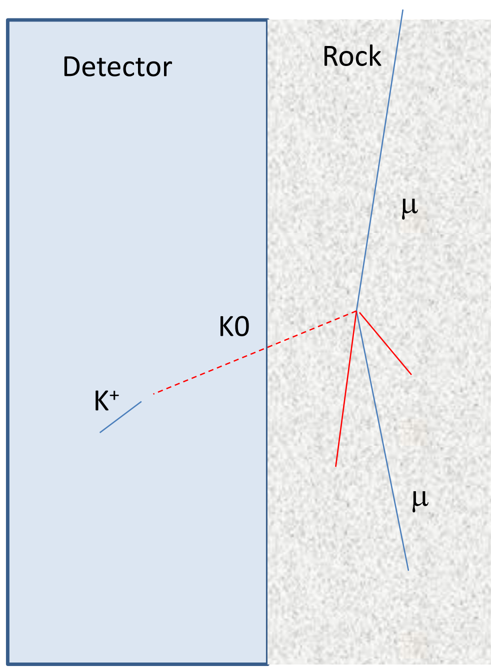

Fig. 1.1.1. Cosmic ray spallation background to proton decay in the p $\rightarrow \nu K^+$.

1.2 Veto Description

The 800 level cavern will be constructed with 3194 veto tubes embedded in the cavern walls as shown in figures 1.2.2 and 1.2.3. Each veto tube consists of a 4 inch square steel tube, 7m long. The cavern and veto tubes are provided by WBS 1.6.

The veto system WBS provides veto counters that are inserted into each square veto tube. A veto counter consists of a 9m long x 8.4cm square PVC extrusion containing liquid scintillator and a loop of wavelength shifting (WLS) fiber. The inside dimensions of the PVC extrusion are 7.8cm x 7.8cm. Both ends of the WLS fiber are attached to a single channel Avalanche Photo-Diode (APD) that is mounted on the extrusion end cap. This design and the cost estimate is adapted from the Nova detector.

Each NOva module consists of 32 detector cells extruded in one piece. The NOva detector cell is 3.7cm x 5.9cm. Each cell contains liquid scintillator and a looped WLS fiber that is routed to a single APD channel. Cosmic ray tests, summarized in figure 1.2.4, have shown that 21 photo-electrons are observed at the APD from a minimum ionizing particle at the far end of the 15.9m long cell. The rms width of the cosmic ray signal is 8 photo-electrons, as shown in figure 1.2.5, or 38%. NOva has set a threshold of 15 photo-electrons, resulting in a 23% inefficiency for minimizing ionizing particles.

We estimate the performance of the proposed veto design by scaling the number of photo-electrons expected in a Nova cell at 9m (41 photo-electrons) by the ratio of the cell inner dimensions for the two cell configurations (1.32 = 7.9cm/5.9cm). We therefore expect 54 photo-electrons and will set the threshold at 15 photo-electrons with a resulting inefficiency of $\approx 10^{-7}$.

The two rows of veto counters are arranged parallel to each other and offset to provide full geometric coverage for cosmic rays at all angles. This configuration does not provide any stereo angle information to determine the distance from the cavern wall to the cosmic ray. Pulseheight information can conceivably be used to accomplish this purpose with an accuracy of a few meters.

The veto system also provides veto tubes and veto counters that provide coverage at the ends of the cavern; the end wall veto. We propose to set two layers of veto tubes on the cavern floor before any equipment is set in place. Approximately 866 veto tubes and veto counters are required to cover both ends of the cavern floor. The veto tube layer would be covered with 1/2” steel plate to provide a means of securing equipment and to prevent inadvertent drilling into a veto counter.

The veto will be implemented in the data acquisition as an additional detector system. The veto detectors will be sampled by ADC’s operating at 2 MHz and merged with the TPC data stream. The veto system will be used to reject a reconstructed K^+ as a proton decay candidate if a nearby veto counter has a pulse height consistent with a minimum ionizing particle.

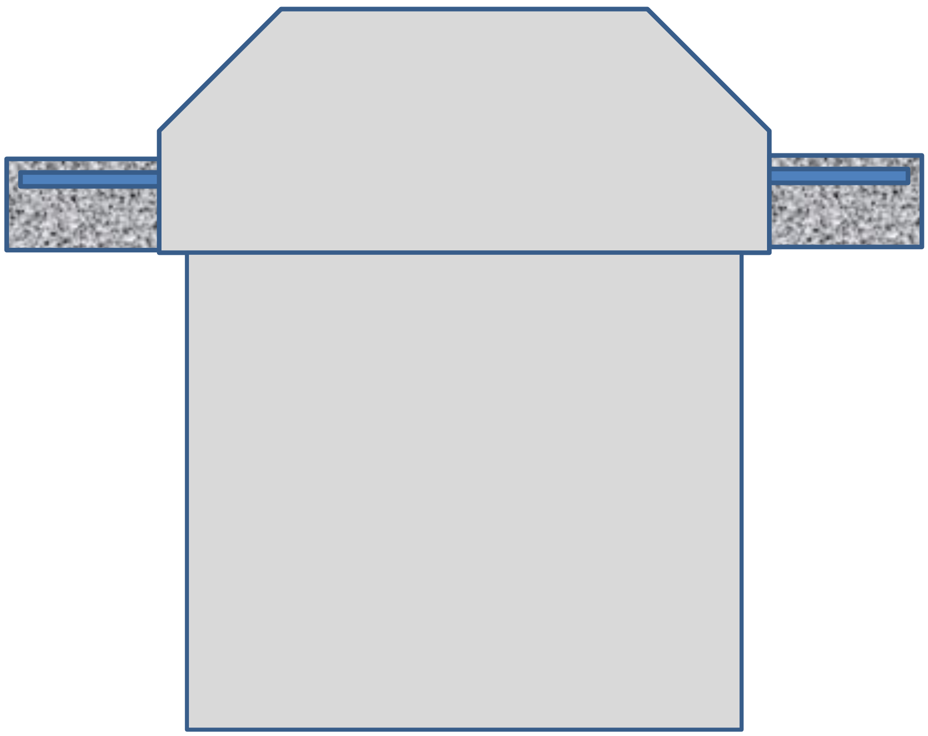

Fig. 1.2.2. End view of the cavern wall showing veto tubes embedded in concrete in the walls of the cavern.

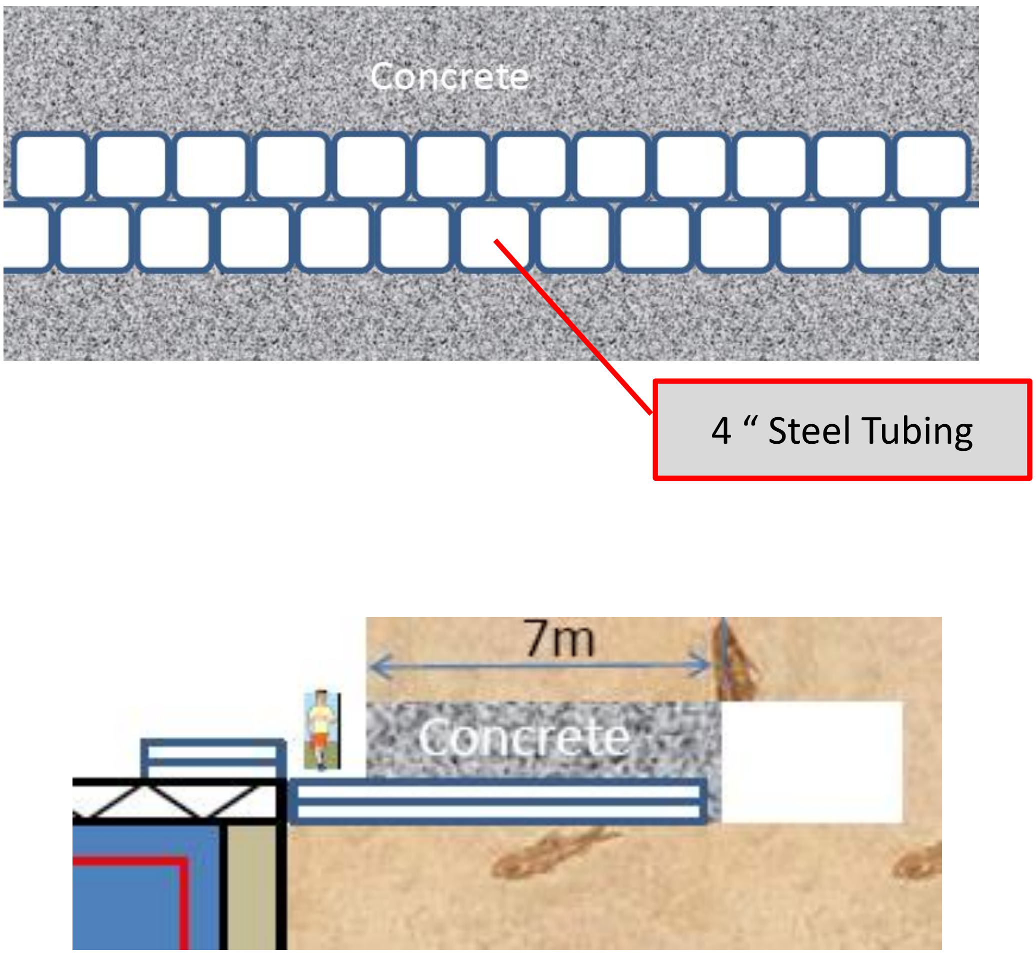

Fig. 1.2.3. Conceptual layout of the veto tubes.

d (m)	pe
0.5	
1.5	94
2.5	78
3.5	68
4.5	61
5.5	55
6.5	49
7.5	45
8.5	41
9.5	38
10.5	35
11.5	32
12.5	30
13.5	27
14.5	25
15.5	23
16.5	21

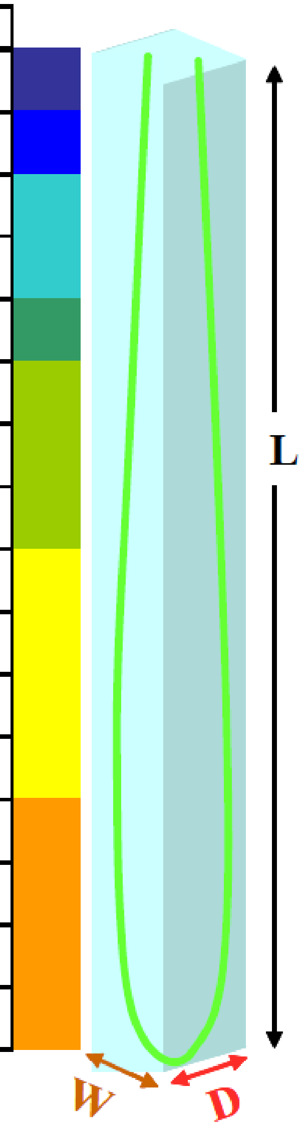

Fig. 1.2.4. The average number of photoelectrons in a Nova cell as a function of distance d from the APD. The cell is broken up into 1 meter long sections. Note the fiber has to exit the cell and run a short distance to the APD, so the effective length of the the cell is longer than the physical 15.7 meters filled with scintillator.

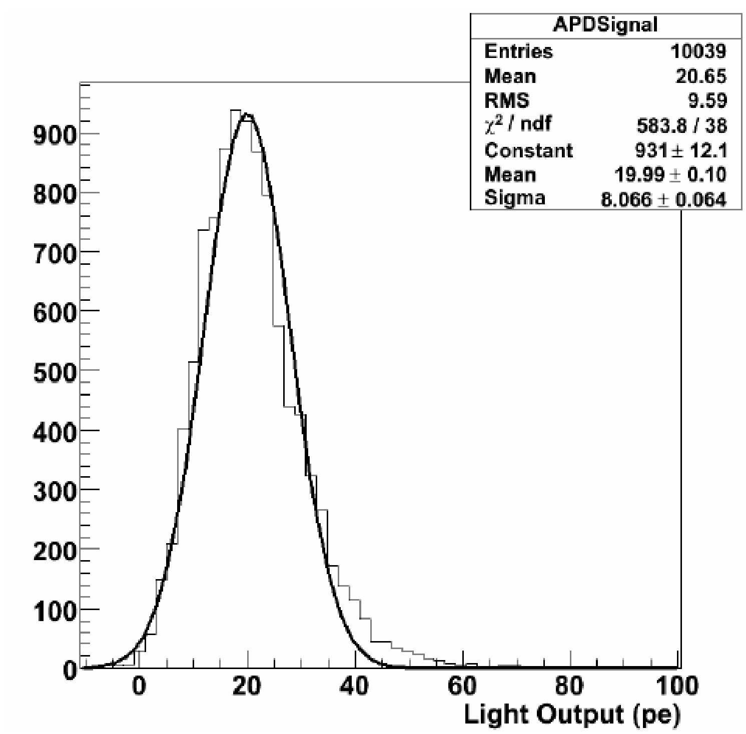

Fig. 1.2.5. Histogram of pulse heights observed in cosmic ray data with a NOva test cell. **FIXME:** *ref nova cdr*